The hydrogen education and research landscape

October 2024 (Report 03)

Disclaimer

The aim of this report is to provide an overview of the training programmes and publicly accessible online educational materials available on the European Hydrogen Observatory, in addition to the trends and patterns in research and innovation activities within the hydrogen sector in Europe as of August 2024, unless stated otherwise. The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completeness of this information.

The data of the European Hydrogen Observatory will continuously be updated. These updates will take place annually for most datasets, while for some it can also be done on a case-by-case basis. As a result, the information used as of writing of this report might differ from the updated data that is presented on the European Hydrogen Observatory.

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Executive summary

This report aims to summarise the status of the European hydrogen education and research landscape. It is based on the information available at the European Hydrogen Observatory (EHO) platform, the leading source of data and information on hydrogen in Europe (EU27, EFTA and the UK). Specifically for education, this report provides an overview of the European training programmes and educational materials available in the EHO library. For research, this report gives insights in the trends and patterns of research and innovation activity in the hydrogen sector based on data of patent registrations and publications. The data is sourced from Tools for Innovation Monitoring (TIM) supplied by the Joint Research Council in August 2024. TIM tracks publications from Scopus and patents from PATSTAT based on keywords.

As of June 2024, a total of 253 European training programmes have been identified. Master's programs and professional training courses constitute the largest segments, accounting for 51% and 33% of the registered programmes, respectively. These programmes are offered in 12 languages, with English being predominant at 51% (130 out of 253 programs). Most programmes (83%) are conducted in a single language, with the remaining 17% being multilingual. The European Hydrogen Observatory has mapped training programmes across 19 countries, with France hosting 37% of the programs, followed by Spain (15%) and the United Kingdom (11%). Interestingly, less than half of the mapped training programmes focus exclusively on hydrogen and/or fuel cells. The predominant subjects covered include hydrogen production and its end-use for transport applications, each represented in 69% of the programmes.

The EHO online library offers 237 reliable educational materials available in various formats, including slides, e-laboratories, experiments, games, case studies, lab protocols, and videos. The library provides resources in 16 different languages, with English being the predominant language, used in 84% of the materials. The primary focus of these educational materials is on hydrogen end-use applications, covered in 36% of the materials. General information on hydrogen follows, included in 27% of the courses. Most materials are intended for audiences at higher education levels, specifically levels 6 and 7, corresponding to Bachelor's and Master's degrees.

From 2006 to 2024, patent and publication activity in the fields of fuel cells, clean hydrogen production, and hydrogen storage was analyzed. In Europe, 20,531 publications and 1,052 patent registrations were identified, representing 23% and 8% of the global totals, respectively. Overall, there is an increasing trend in publications, while patent activity shows a declining trend. Fuel cells dominated the research landscape in the early years, but there has been progressively a significant shift toward hydrogen production.

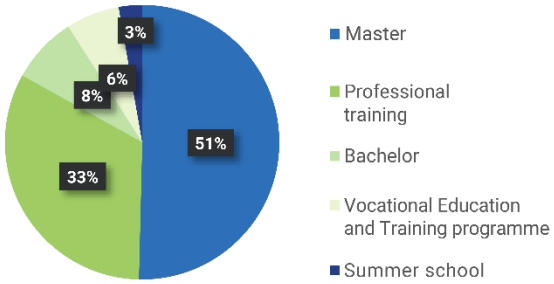
Key insights

Training Programmes & Education Materials

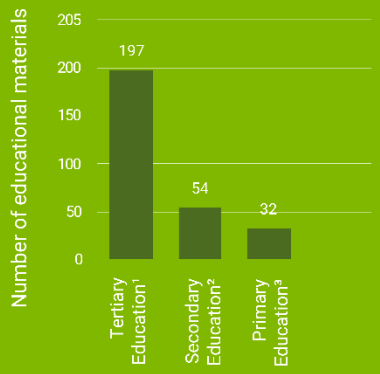
253 training programmes & 237 educational materials available in the EHO database online library.

Training programmes available in **12 languages** and educational materials in 16, with over 50% offered in **English**.

Training programmes by type



Education materials by level

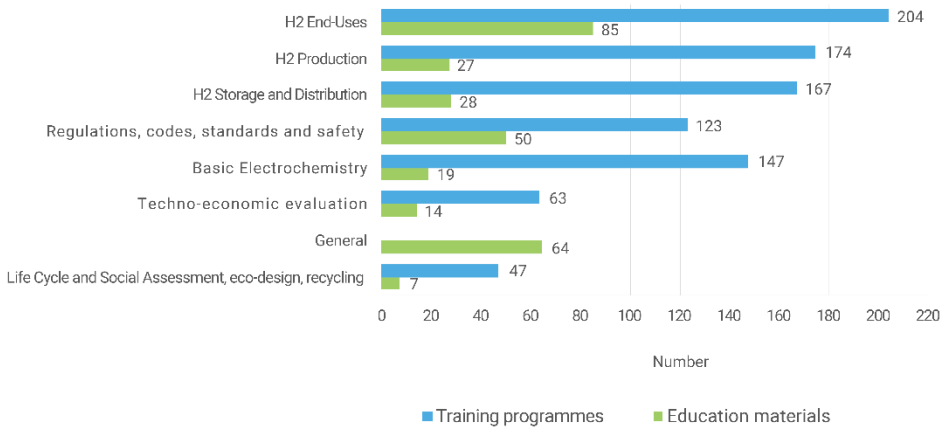


¹ Short-cycle programmes, bachelor's, master's, and doctoral degrees (ISCED 5–8)
² High school and post-secondary non-tertiary education (ISCED 3–4)
³ Primary school and middle school (ISCED 1–2)

The majority of the materials are intended for audiences with higher level of understanding, specifically **Bachelor's and Master's levels.**

63% of the training programmes are taking place in **France, Spain and UK.**

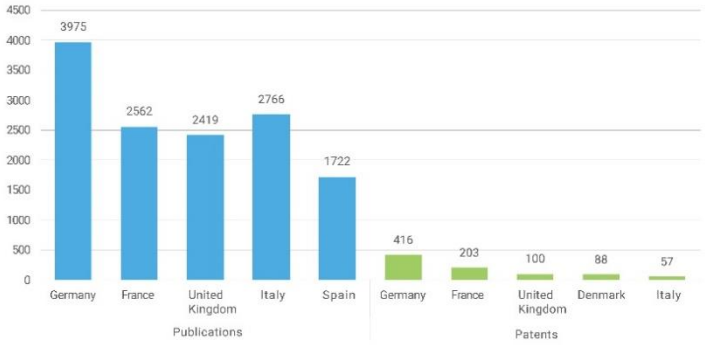
Training programmes and education materials by topic



Publications & Patents

The publication and patent data cover **fuel cell** (PEM, SO and alkaline), **clean hydrogen production** (PEM, SO, alkaline and non-elecrolysis) and **hydrogen storage** (only onboard storage) sectors.

Top 5 European countries in publications and patents

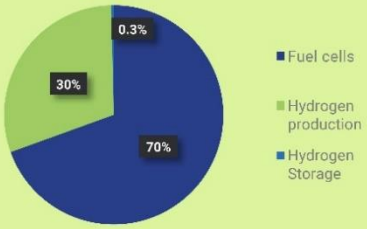


Hydrogen production has gained **increasing importance** in recent years in the **research** landscape **compared to fuel cells.**

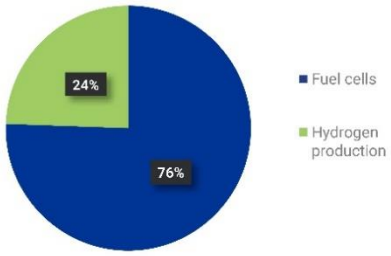
A total of **20,531 publications** been identified in Europe from 2006 to 2024

A total of **1,052 patents** have been identified in Europe from 2006 to 2023

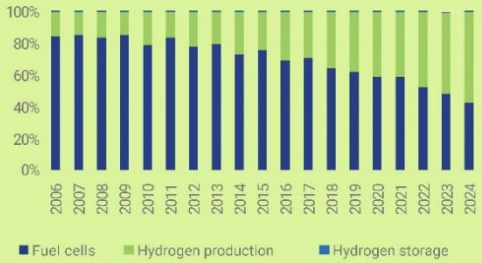
Publications in Europe by topic



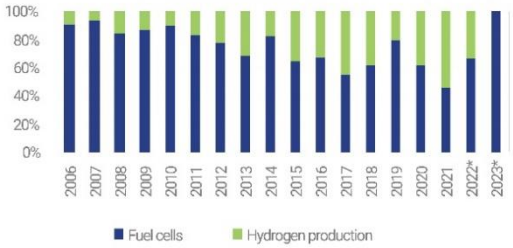
Patents in Europe by topic



Historical data of publications in Europe by topic from 2006 to 2024



Historical data of patents in Europe by topic from 2006 to 2023



* Patents are published 18 months after filing, so data for 2022 and 2023 may not yet be fully complete.

Overview

In the rapidly evolving landscape of modern industries, education and research are crucial for fostering innovation, workforce readiness, and economic growth. As the global focus shifts towards sustainability and renewable energy, hydrogen technology demands robust educational frameworks, comprehensive training programmes, and cutting-edge research.

Education provides essential knowledge for advancing hydrogen technologies, with specialized programmes preparing individuals for hydrogen production, distribution, and end-use. Training programmes bridge theory and practice, equipping the workforce with practical skills and facilitating the re-skilling of workers from declining industries, thereby promoting job creation and economic resilience. Research drives continuous innovation in hydrogen technologies, leading to efficiency improvements, cost reductions, and solutions to technical challenges. Patents protect intellectual property and publications disseminate new knowledge, fostering further industry innovation.

The synergy between education and research creates a robust ecosystem supporting the hydrogen sector's development. By investing in these areas, stakeholders can ensure the growth of the hydrogen economy and its contribution to global sustainability goals.

This report includes information on European training programmes, educational materials and the trends and patterns of research and innovation activity in the hydrogen sector with data of patent registrations and publications. It is based on the information available at the European Hydrogen Observatory (EHO) website (https://observatory.cleanhydrogen.europa.eu/), the leading source of hydrogen data in Europe. The data presented in this report is based on research conducted until the end of August 2024.

The training programmes section provides insights into major European training initiatives, categorized by location. It allows filtering by type of training, focus area and language. It covers a wide range of opportunities such as vocational and professional trainings, summer schools, and Bachelor's or Master's programmes.

The education materials chapter summarizes the publicly accessible educational materials available online. Documents can be searched by educational level, by course subject, by language or by the year of release.

The section referring to research and innovation activity analyses trends and patterns in the hydrogen sector, using aggregated datasets of patent registrations and publications by country.

01

Training programmes

Introduction

This chapter provides an overview of the European training programmes that are registered in the EHO database and are relevant to the hydrogen sector. This chapter provides statistics of the training programmes based on location, the type of training, focus of the training and language.

The data on training programmes presented on the European Hydrogen Observatory website are shared by training providers and processed by Hydrogen Europe Research and reflects the situation as of June 2024. The information is provided by organizations and individuals through completion of our questionnaire. For a training programme to be listed, it must include a minimum set of information and web references to facilitate posting.

Interactive data dashboards on training programmes can be accessed on the European Hydrogen Observatory website.

1.1. Overview

Currently, 253 training programmes are listed in the Observatory's online library.

Table 1, gives an overview of the different filters available in the training programmes dashboard, allowing users to refine their search according to specific needs. Users have the ability to filter their search results based on three criteria: type of training (5 options), course focus (11 subjects), and language availability (12 languages).

In addition to the three criteria mentioned above, organizations and individuals are able to provide additional information about their training programmes. Table 2 presents the extra information a training programme may provide in the EHO database, that can be seen by the user when navigating though the library, such as the name of the organization, target audience, training duration and many more.

Table 1. Filters on training programmes available on the EHO website.

Type of training	Course focus	Language
Bachelor Master Professional training Summer school Vocational Education and Training (VET) programmes	Basic electrochemistry H_2 End-uses: buildings H_2 End-uses: energy, power generation H_2 End-uses: industry H_2 End-uses: transport H_2 Production H_2 Storage, Transport and Distribution Life Cycle and Social Assessment, eco-design, recycling Regulations, Codes, Standards Safety Techno-economic evaluation	Danish Dutch English French German Greek Italian Norwegian Portuguese Romanian Spanish Swedish

Table 2. Additional information data providers may provide for training programmes.

Additional information on training programmes	
Question	**Answer**
Name of the organization providing the training	e.g. Université Grenoble Alpes
Location (address):	• For in-person training: address where the training takes place • For online training: location of the training provider
Is the programme entirely focused on hydrogen and/or fuel cells?	• Yes • No
Target audience for the training	E.g., Master students in engineering, electricians, trainers, etc.
How is the training taught?	• In person • Online • Hybrid / both options possible
Requirements from applicants	Minimum degree, prerequisite to attend the training, etc.
Materials / Infrastructures proposed	• Books / e-books • Demonstration platforms • E-Learning tools e.g. MOOCs • Handouts • Infrastructure visits • Labs (physical or virtual) • Serious games • Simulation environment • Slides
Duration of the training	• One day or less • Between a day and a week • Between one week and a month • Between one and six months • Between six months and a year • Between one and two years • More than two years
Recognition of the training	Issuance of a certificate by the organisation, obtention of a recognised degree, ECTS or ECVET granted, microcredentials, other
Is the programme complimentary?	• Yes • No
If the programme is not complementary, how much does it cost?	e.g. cost in €
Capacity of the training	Maximum number of participants
Possibility to combine the training with employment	Description of the relevant scheme applying: apprenticeship, evening classes, study time arranged to combine the training with work etc.

1.2.
Training programmes by category

1.2.1.
Training programme type

Figure 1 shows the various training programme types and their respective shares of the total number of training programmes listed in the EHO database. These categories include bachelor's, master's, VET programmes, professional trainings, and summer schools.

Master's programmes represent the largest segment among the registered training programmes, totalling 128, which accounts for 51% of the total. Professional training programmes follow with 83 entries, comprising 33% of the total, while the remaining categories collectively make up approximately 17% of the programmes.

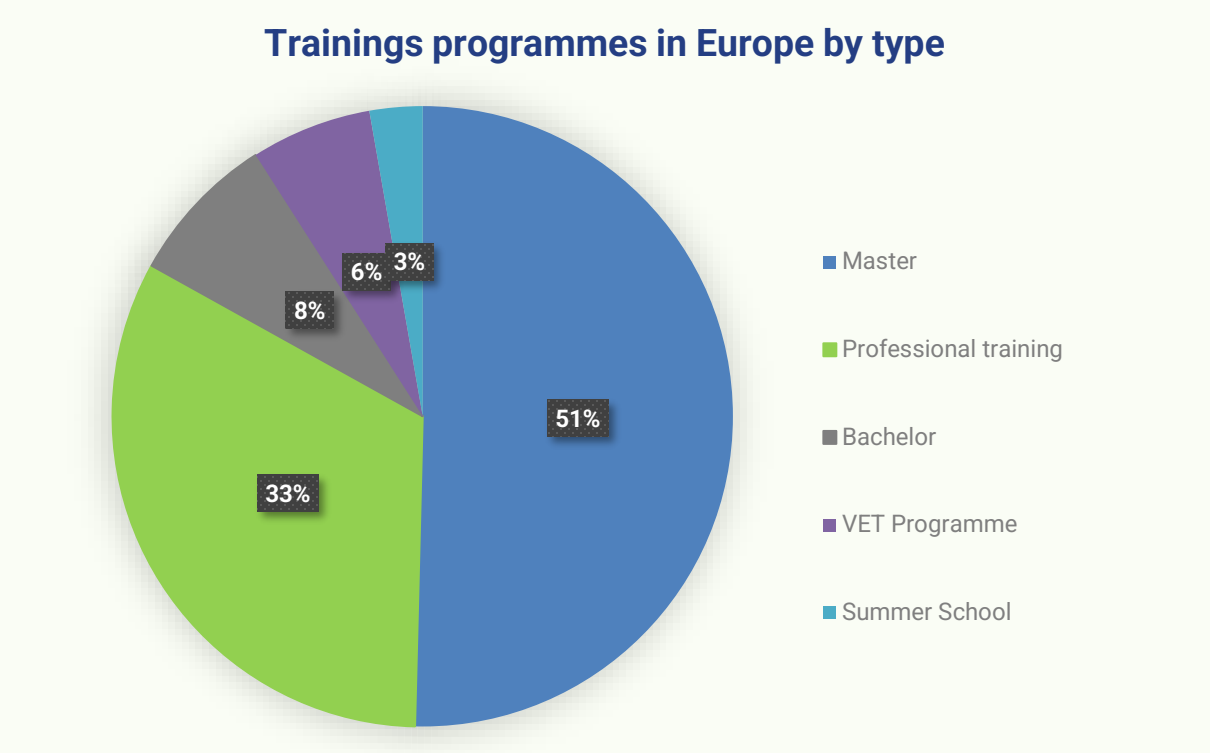


Figure 1. Share of training programmes in Europe by type.

Figure 2 illustrates the evolution of the training programmes registered in the EHO database from 2021 to 2023. The Master's programmes exhibited substantial growth, increasing by 137% over the two-year period and by over 9% from 2022 to 2023, reaching a total of 128 programmes in 2023. Professional training programmes also demonstrated a rising trend, growing by 77% from 2021 to 2023 and by more than 14% from 2022 to 2023, resulting in 83 programmes in 2023. Bachelor's programmes saw an increase of over 83% from 2021 to 2022, followed by a 9% decrease in 2023, totalling 20 programmes. VET programmes experienced a steady rise of over 128% from 2021 to 2023 and by more than 45% from 2022 to 2023, totalling 16 programs. Summer school programmes remained stable from 2021 to 2022, with a subsequent 40% increase in 2023, totalling 7 programmes.

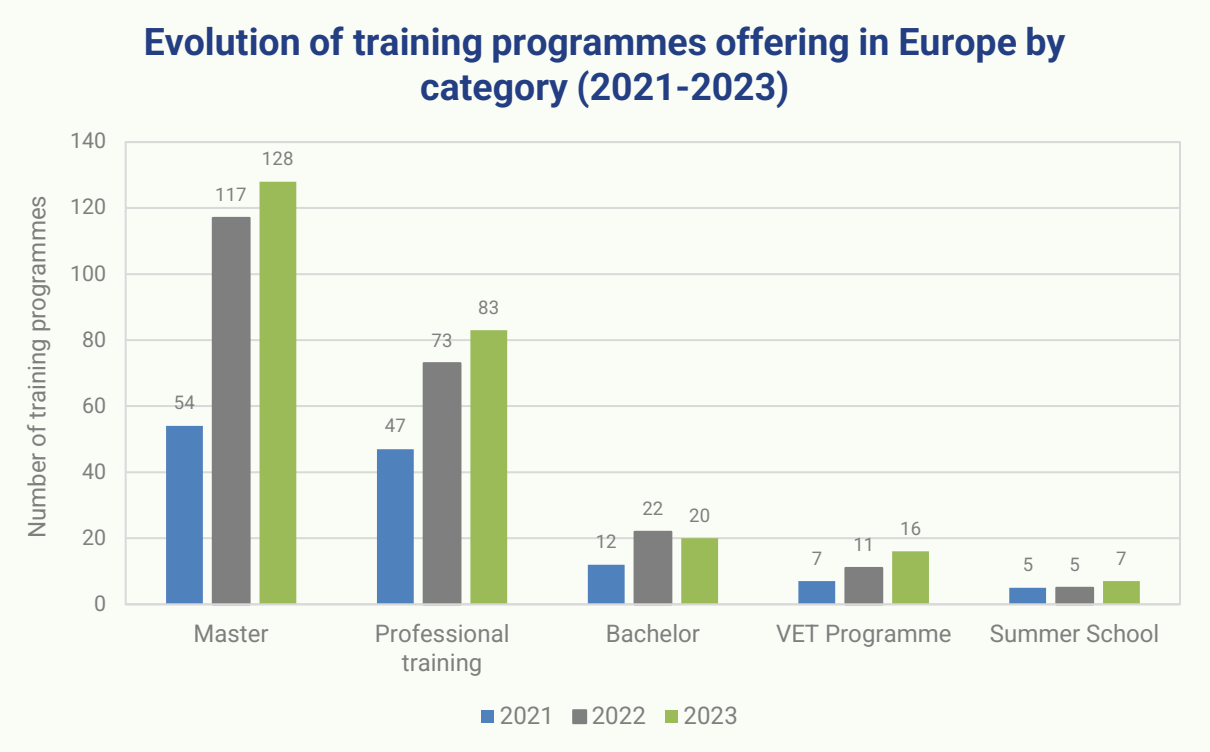


Figure 2. Evolution of training programmes offerings in Europe by category (2021-2023).

1.2.2.

Language

The registered training programmes provide learning opportunities in 12 different languages. Figure 3 presents a summary of the languages in which the programmes are most abundantly available. Note that some programmes are available in multiple languages, so the counts reflect the availability in each language.

English is the predominant language, used in 51% of the programmes (130 out of 253). French follows as the next most common language, utilized in 32% of the programmes. Spanish is available in 12% of the programmes, while German is offered in 9%. Italian and Dutch are each available in 4% of the programmes. Other languages, including Greek, Norwegian, Portuguese, Romanian, Swedish, and Danish, are collectively available in less than 5% of the training programmes mapped.

It is also worth noting that not all countries with training programmes offer them in the local language. Some programmes are conducted in English, especially those under international schemes like Erasmus Mundus Masters. Additionally, certain programmes are available both in English and in the local language of the country where the training takes place.

As shown in Figure 4, the majority of the programmes mapped (83%) are conducted in a single language, comprising 211 programmes, with the remaining 17% being multilingual, totalling 42 programmes. Multilingual usually means bi-lingual, in English and the language of the country where the training takes place.

Figure 3. Breakdown of training programmes in Europe available in the EHO library by language [1].

[1] The abbreviations used in this figure refer to the country codes used by Eurostat and available here: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Country_codes

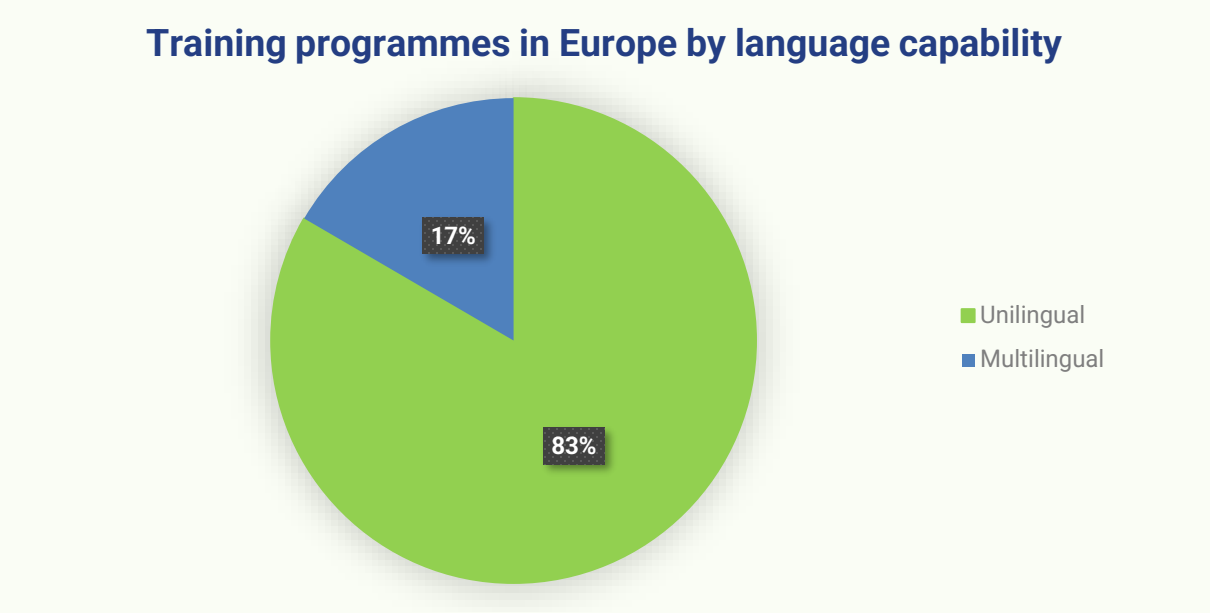


Figure 4. Share of training programmes in Europe by language capability.

1.2.3.

Location

The Observatory's mapping of training programmes covers 19 countries. Figure 5 provides an overview of the geographical distribution of training programmes categorized by ranges of programme numbers, while Figure 6 details the number of programmes per country.

The training programmes are predominantly located in France where 37% of the trainings are taking place, followed by Spain (15%) and then United Kingdom (11%). Between 5 and 10% are found in Germany (8%), Italy (7%), and the Netherlands (6%). As a general tendency that trainings in the field of hydrogen seem to be more often provided in Western Europe. It is important to note that the EHO database may not capture all available training programmes. Training providers are encouraged to register their programmes by filling out the provided form.

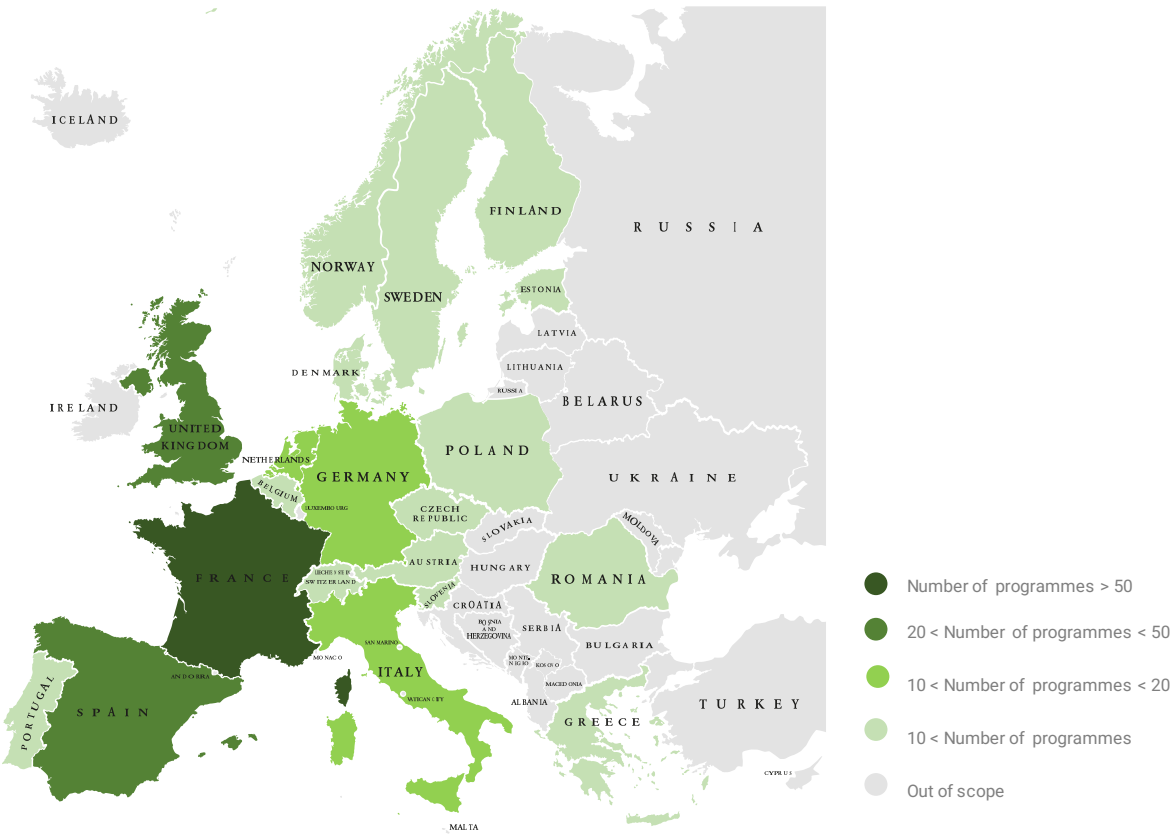


Figure 5. Geographical distribution of training programmes in Europe by ranges.

Figure 6. Number of training programmes in Europe by country.

1.2.4.

Training focus

Most of the mapped training programmes are not entirely focused on hydrogen and/or fuel cells. As shown in Figure 7, fewer than half of the programmes (119 out of 253) concentrate solely on hydrogen and fuel cells. The remaining programmes cover broader subjects, with hydrogen and fuel cells being only a part of the overall curriculum.

Table 3 provides an overview of the available subject categories related to the hydrogen topic, including detailed explanations for each item. Figure 8 illustrates the number of training programmes associated with each of these subject categories. It is important to note that most programmes address multiple topics, so the counts represent the extent to which each topic is included in the programmes.

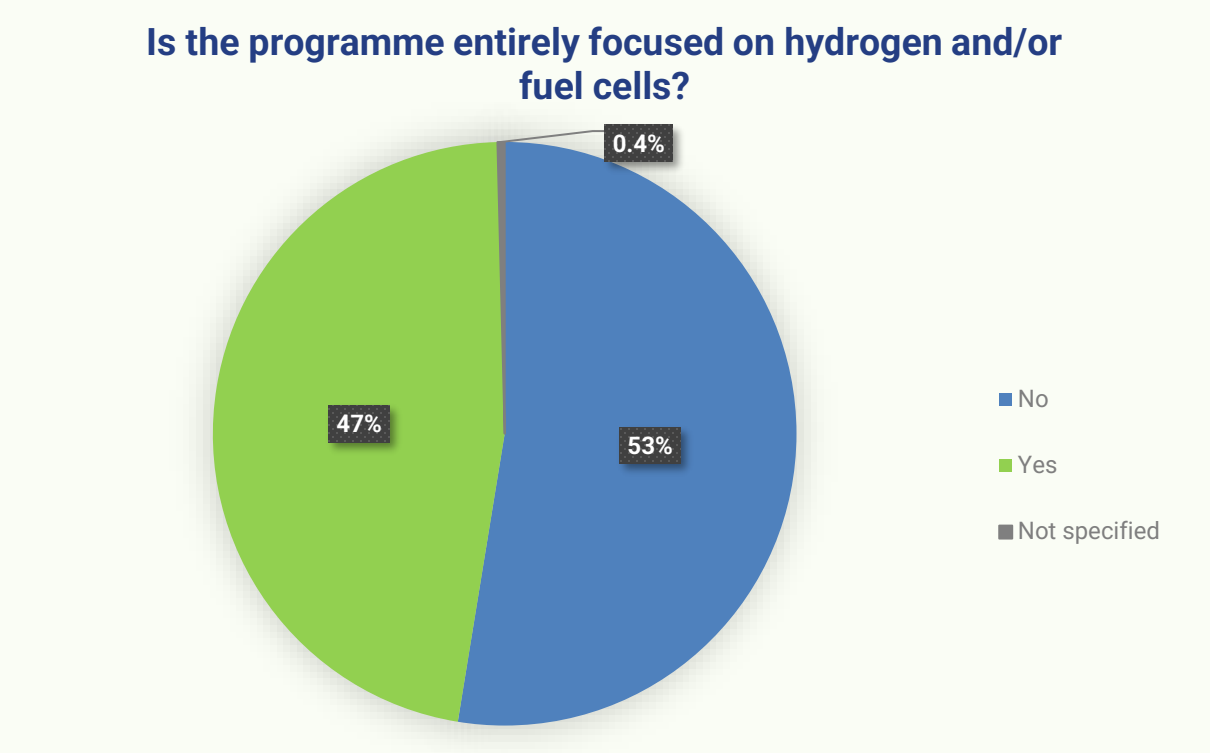


Figure 7. Share of programmes entirely focused on hydrogen and/or fuel cells.

Table 3. Overview of training programmes subject categories.

Training focus	Description
Basic Electrochemistry	Refers to the theory behind the electrochemical reactions that are taking place in electrolysis or fuel cell devices.
H_2 Production	Refers to the different means to produce hydrogen (electrolysis, gasification of biomass, pyrolysis, etc.)
H_2 Storage, Transport and Distribution	Refers to the methods used to store, transport and distribute hydrogen (e.g. storage in salt cavern, transport via pipelines, etc.)
H_2 End-uses: transport	Refers to vehicles using hydrogen or hydrogen derivative synthetic fuels in fuel cells or ICE. All transport sectors are included: road, maritime, aviation, rail and off-road.
H_2 End-uses: industry	Refers to hydrogen used in some industrial processes (e.g. steel manufacturing, chemicals, etc.)
H_2 End-uses: buildings	Refers to electrical, heating and cooling applications including fuel cells, CHP, boilers, etc. using hydrogen or hydrogen derivative synthetic fuels.
H_2 End-uses: energy, power generation	Refers to the production of electricity using hydrogen or hydrogen derivative synthetic fuels in turbines and/or fuel cells.
Regulations, Codes, Standards	Refers to the applicable regulations and the development and use of harmonized performance-based standards for hydrogen appliances and systems.
Safety	Refers to the safe production, handling and use of hydrogen or its derivatives.
Life Cycle and Social Assessment, eco-design, recycling	Refers to environmental and sustainability aspects of hydrogen.
Technical-economic evaluation	Refers to training courses at the crossroad of business and engineering to evaluate the technical possibilities of the technology whilst considering its economic cost.

Hydrogen production and its end-use applications in transportation are the predominant subjects, each covered in 69% of the programmes. The storage, transport, and distribution of hydrogen follow closely, being covered in 66% of the programmes. Basic electrochemistry and end-use applications in energy and power generation are covered by 58% and 53% of the programmes, respectively.

Other subjects are covered less frequently: safety (44%), end-use applications in industry (38%), end-use applications in buildings (33%), regulations, codes, and standards (25%), techno-economic evaluation (25%), Life Cycle and Social Assessment, and eco-design and recycling (19%)

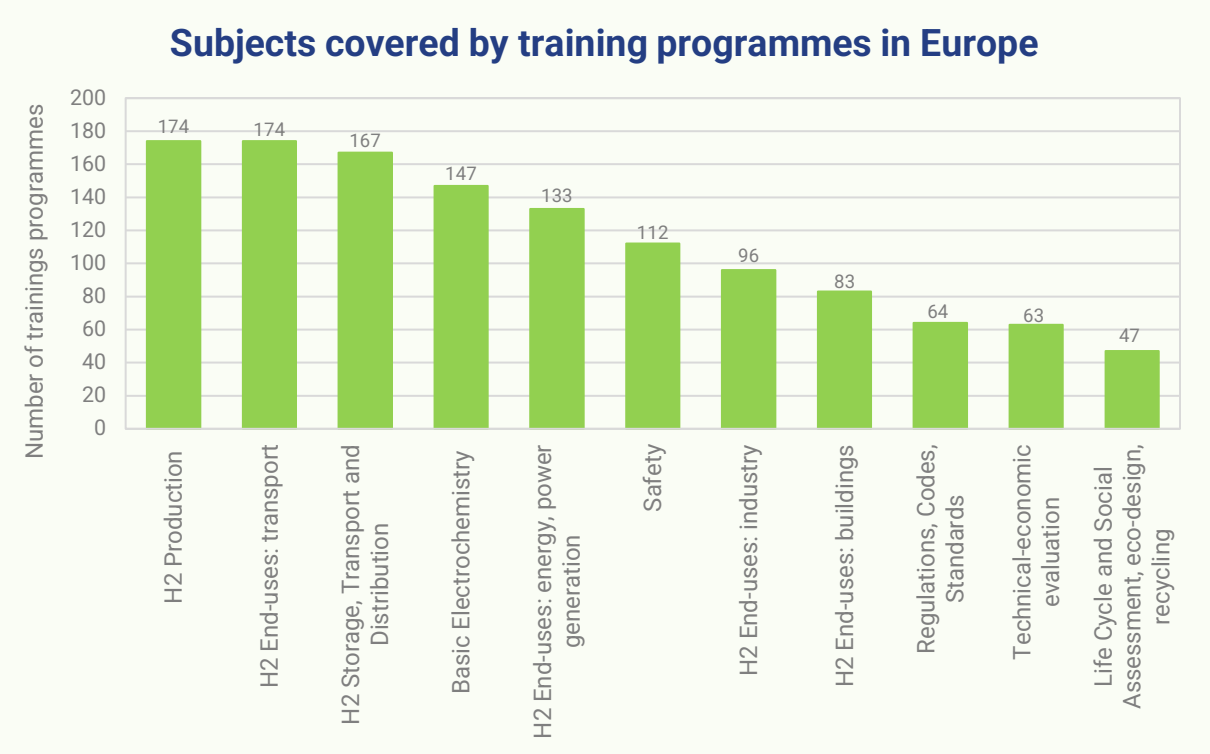


Figure 8. Number of training programmes in Europe by subject.

02

Education materials

Introduction

This chapter provides an overview of the current education materials in the EHO database for learners and students interested in the field of hydrogen.

The EHO database provides an online library relevant for all different levels of education, as described by the International Standard Classification of Education (ISCED) and covers many different course subjects and languages. Only materials intended for public use are shared in the library.

The data on educational materials presented on the European Hydrogen Observatory website are collected by Hydrogen Europe Research from European projects' deliverables (Clean Hydrogen Partnership and other EU programmes) as well as other reliable sources identified through desk research and reflects the situation as of June 2024. Individuals and organizations wishing to contribute to this open-access library are encouraged to contact the EHO team.

Interactive data dashboards on education materials can be accessed on the European Hydrogen Observatory website.

2.1. Overview

237 reliable materials may be retrieved on the online library of the EHO. It is the go-to-resource for finding hydrogen related materials developed in the framework of European projects.

Table 4 provides an overview of the filters that are available to refine the search of users according to their needs. The filters include the education level (ranging from 0 to 8 ISCED level), the course focus, and the language.

The International Standard Classification of Education (ISCED) levels, developed by UNESCO, is an internationally recognized system that categorizes education programs and qualifications by level and field, enabling consistent comparison across different education systems globally. By aligning the materials with each ISCED level, a clear and structured understanding of the various stages of education is provided.

Table 4. Categories on educational materials available on the EHO website.

Level of education	Course focus	Language
ISCED 0: Early childhood education	Basic electrochemistry	Czech
ISCED 1: Primary education (primary school)	General	Danish
ISCED 2: Lower secondary education (middle school)	H_2 Production	Dutch
ISCED 3: Upper secondary education (high school)	H_2 Storage and Distribution	English
ISCED 4: Post-secondary non-tertiary education	H_2 End-uses	French
ISCED 5: Short-cycle tertiary education	Life Cycle and Social Assessment, eco-design, recycling	German
ISCED 6: Bachelor's or equivalent level	Regulations, Codes, Standards & Safety	Greek
ISCED 7: Master's or equivalent level	Techno-economic evaluation	Hungarian
ISCED 8: Doctoral or equivalent level		Italian
		Norwegian
		Polish
		Portuguese
		Romanian
		Serbian
		Spanish
		Turkish

Additionally, users can search for relevant materials based on their release year. The educational materials available were created between 2006 and 2024. Figure 9 illustrates the number of educational materials released within this period. The highest number of materials were released in 2024 (50 materials), 2006 (43 materials), 2012 (38 materials) and 2019 (32 materials). Conversely, the fewest materials were released between 2015 and 2018, with fewer than five materials released each year.

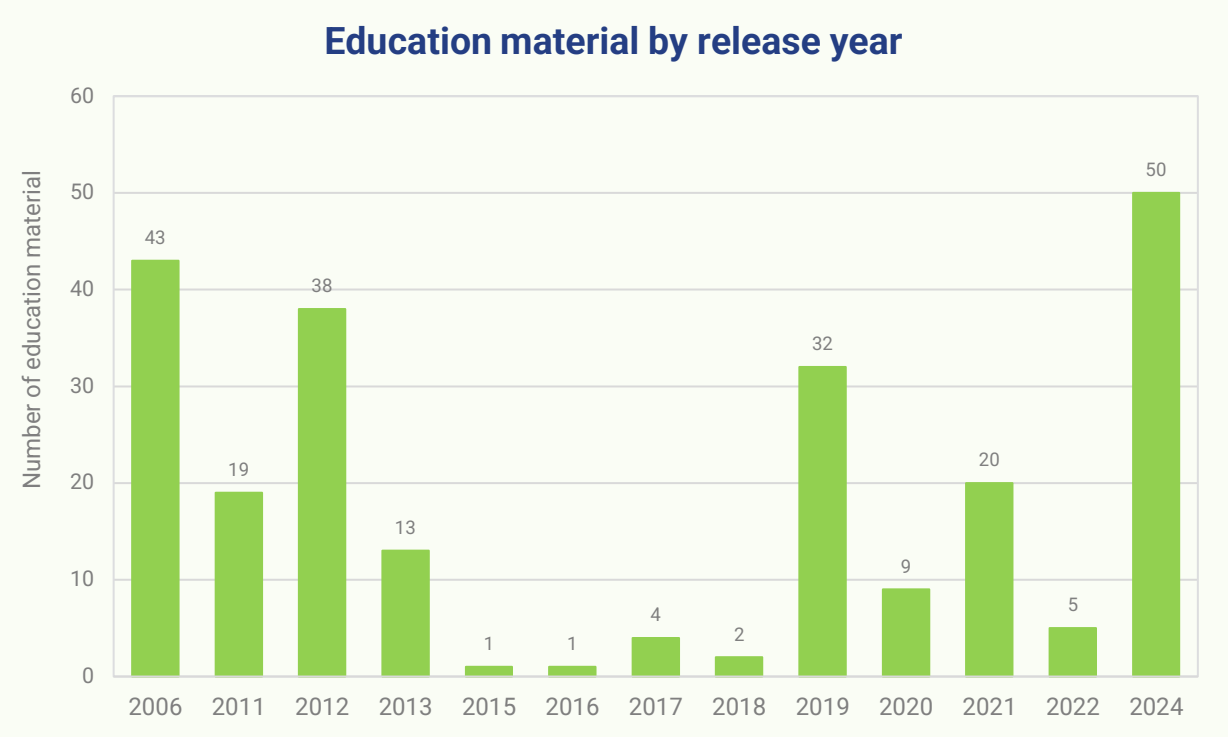


Figure 9. Number of education materials released by year.

The educational materials are available in various formats, mainly slides, but also e-laboratories, experiments or games, case studies, lab protocols, videos and more.

The sources include CertifHy, CLEAN-kWAT, College of the Desert and SunLine Transit Agency, ene.field, FCH Train, FCHGO, GreenSkillsforHydrogen, H_2 Training, HyFacts, HyResponder, HySchools, Jess Summer School 2011 and 2012, JUST GREEN AFRH2ICA, NET-Tools, PACE, SkillSea, Sustainability by Biotechnology, UpHyMob and US Department of Energy.

2.2.

Education materials by category

2.2.1.

Language

Education materials spanning 16 different languages are currently listed in the EHO library. Those languages include Czech, Danish, Dutch, English, French, German, Greek, Hungarian, Italian, Norwegian, Polish, Portuguese, Romanian, Serbian, Spanish and Turkish.

Figure 10 displays the languages in which educational materials are available in the EHO library. Note that some materials are available in multiple languages, so the counts reflect the availability in each language.

English is the predominant language, available for 84% of the materials (199 out of 237). Italian follows with 21% (49 materials), Spanish and French with 17% each (40 and 41 materials, respectively) and German with 16% (38 materials). Less than 10% of the materials are available in the remaining languages.

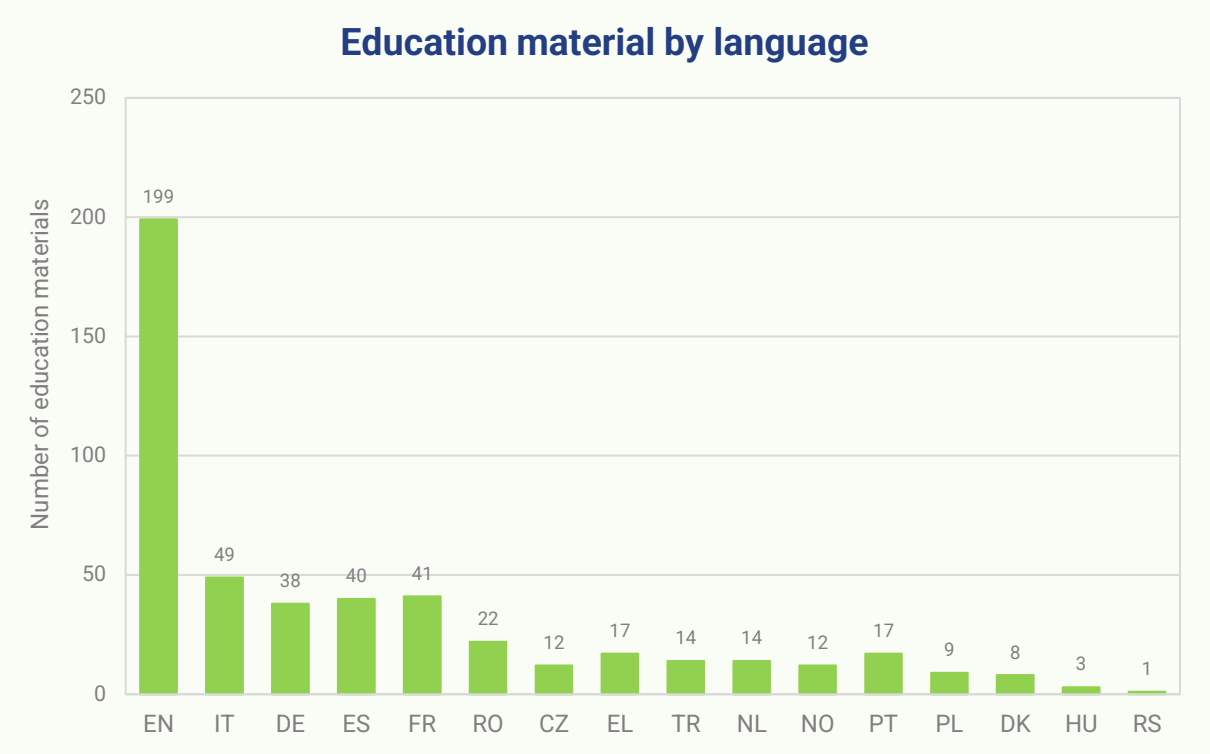


Figure 10. Breakdown of education materials available in the EHO library by language[2].

2.2.2.

Course topic

Like the training programmes, the education materials are categorized according to their course topics. Table 5 provides a comprehensive overview of these topics, including detailed explanations for each.

[2] The abbreviations used in this figure refer to the country codes used by Eurostat and available here: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Country_codes

Figure 11 illustrates the number of courses that each topic is applicable to. It is important to note that most courses address multiple topics, so the counts represent the extent to which each topic is included in the courses.

Table 5. Overview of available education material topics.

Course topic	Description
General	Refers to information remaining at a broad level of understanding, not going into technical details.
Basic Electrochemistry	Refers to the theory behind the electrochemical reactions that are taking place in electrolysis or fuel cell devices.
H_2 Production	Refers to the different means to produce hydrogen (electrolysis, biomass gasification, pyrolysis, etc.)
H_2 Storage and Distribution	Refers to the methods used to store, transport and distribute hydrogen (e.g. storage in salt cavern, transport via pipelines, etc.)
H_2 End-Uses	Refers to hydrogen usages in transport, industry, buildings or to generate power.
Regulations, codes, standards and safety	Refers to the applicable regulations and the harmonized performance based standards for hydrogen appliances and systems, as well as the safe production, handling and use of hydrogen, particularly hydrogen gas fuel and liquid hydrogen.
Life Cycle and Social Assessment, eco-design, recycling	Refers to environmental and sustainability aspects of hydrogen.
Techno-economic evaluation	Refers to training courses at the crossroad of business and engineering to evaluate the technical possibilities of the technology whilst considering its economic cost.

Hydrogen end-use applications is the predominant topic, covered in 36% of courses. General information on hydrogen is included in 27% of courses. Regulations, codes, standards, and safety are addressed in 21% of courses, while hydrogen storage and distribution is covered in 12% of courses.

Other topics include hydrogen production (11%), basic electrochemistry (8%), techno-economic evaluation and Life Cycle and Social Assessment (6%), and eco-design and recycling (3%).

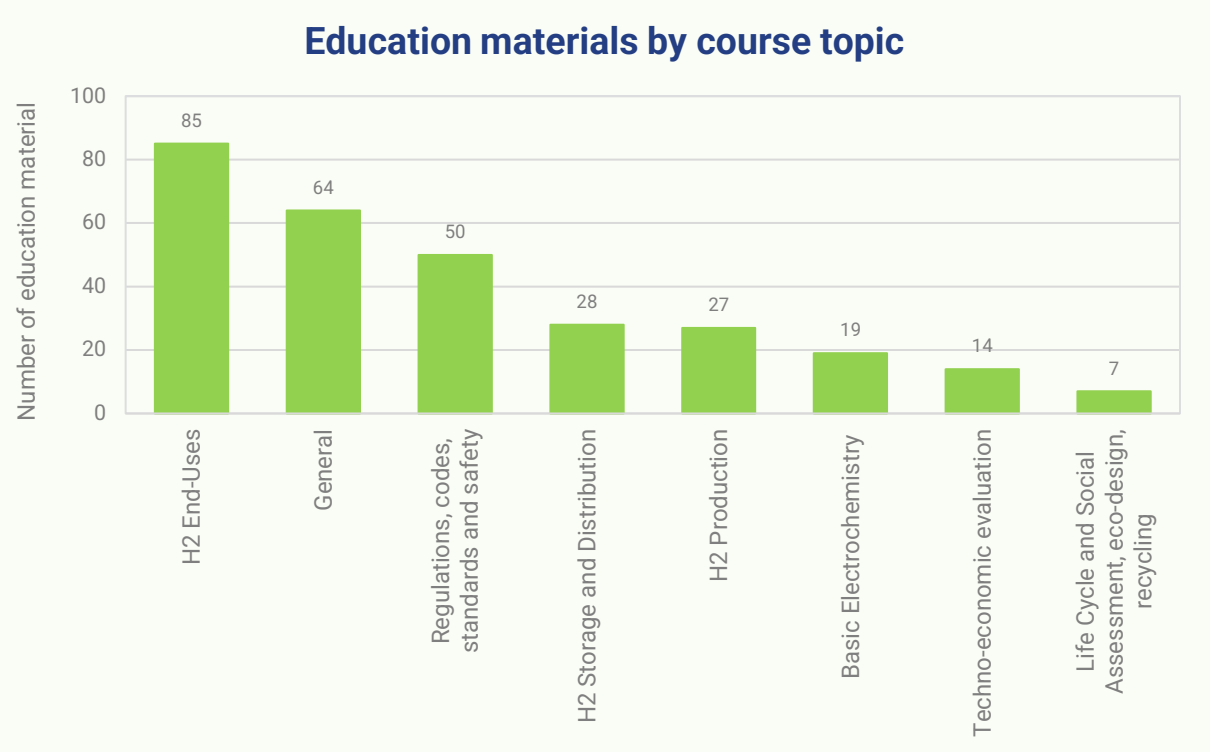


Figure 11. Educational materials available in the EHO library by topic.

2.2.3.

Education level

This section provides a comprehensive overview of educational materials, organized by the ISCED framework.

Figure 12 displays the number of educational materials categorized by ISCED level, ranging from level 1 to 8. The descriptions of each ISCED level are provided in the introduction of this chapter. It is important to note that most courses address multiple topics, so the counts represent the extent to which each topic is included in the courses.

As illustrated in Figure 12, most of the materials are intended for audiences with higher levels of understanding. ISCED 6 is the predominant education level, targeted by up to 65% of the courses. This is followed by ISCED 7, associated with 55% of the educational materials. Additionally, ISCED 5 is targeted by 48% of the materials.

It is also worth noting that lower-level education is targeted in several courses. These courses are often translated into different languages to ensure accessibility for various national audiences. However, the educational materials available in the EHO library do not target early childhood education (ISCED 0), as hydrogen-related topics are relatively complex and not yet suited for this age group.

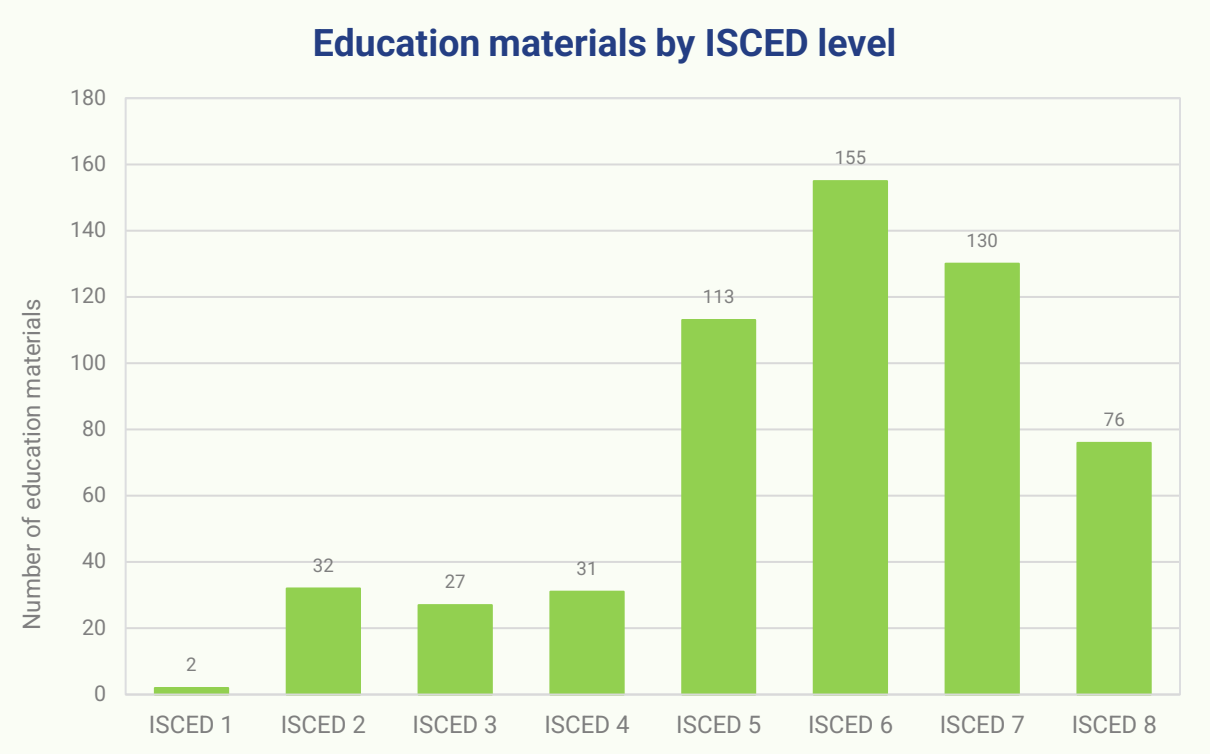


Figure 12. Number of education materials by ISCED level.

03

Research and innovation activity

Introduction

This chapter provides an overview of trends and patterns in research and innovation activity in the hydrogen sector, using aggregated datasets of patent registrations and publications by country.

Data for patents and publications is sourced from Tools for Innovation Monitoring (TIM) supplied by the Joint Research Council in August 2024. TIM tracks publications from Scopus and patents from PATSTAT based on keywords. The data summarized from the TIM datasets encompasses patents and publications as of 2006 and will be updated annually. The data are categorized into three main topics: (1) fuel cells, which include Solid Oxide (SO), Proton Exchange Membrane (PEM), and alkaline technologies; (2) hydrogen production, encompassing SO, PEM, and alkaline electrolysis as well as other clean production methods; and (3) hydrogen storage, focusing specifically on onboard storage solutions. It is acknowledged that when conducting searches, duplicates may exist between the different TIM 'spaces' (categories) as for example, one patent or publication might cover both SO and PEM fuel cell technologies. Nevertheless, duplicates cannot exist within the same dataset and therefore we believe that the TIM data is an accurate way to portray trends in patents and publications within the hydrogen topic. Fractional counting is used to determine the number of patents and publications per country for patents filed and publications written by institutions from multiple countries.

For more information on hydrogen patent activity, we recommend the 'Hydrogen patents for a clean energy future' report of the IEA and EPO, which provides the most comprehensive and up-to-date global review of patenting trends in a broad range of technologies.

Interactive data dashboards on patents and publications can be accessed on the European Hydrogen Observatory website.

3.1. Publications

The scientific and technical literature on hydrogen spans a wide range of topics, reflecting the multidisciplinary efforts to harness its potential. Publications in this field highlight significant advancements in technologies such as electrolysis, fuel cells, and hydrogen storage materials. They also address the challenges and opportunities in scaling up hydrogen production, improving efficiency, and integrating hydrogen into existing energy infrastructures.

This dataset seeks to identify emerging research trends in the hydrogen sector.

A total of 88,862 publications worldwide have been identified from 2006 to 2024 in the fields of fuel cells, clean hydrogen production, and hydrogen storage. Figure 13 illustrates the geographical distribution of these publications, focusing on Europe (EU27, EFTA, and UK) and the rest of the world, as well as the distribution of publications by topic.

Publications in Europe account for a smaller share of the global total, comprising 20,531 (23%). Within Europe, the predominant topic is fuel cells, which represent 70% of the publications, totalling 14,263. The remaining publications primarily focus on hydrogen production and in a small extent on storage.

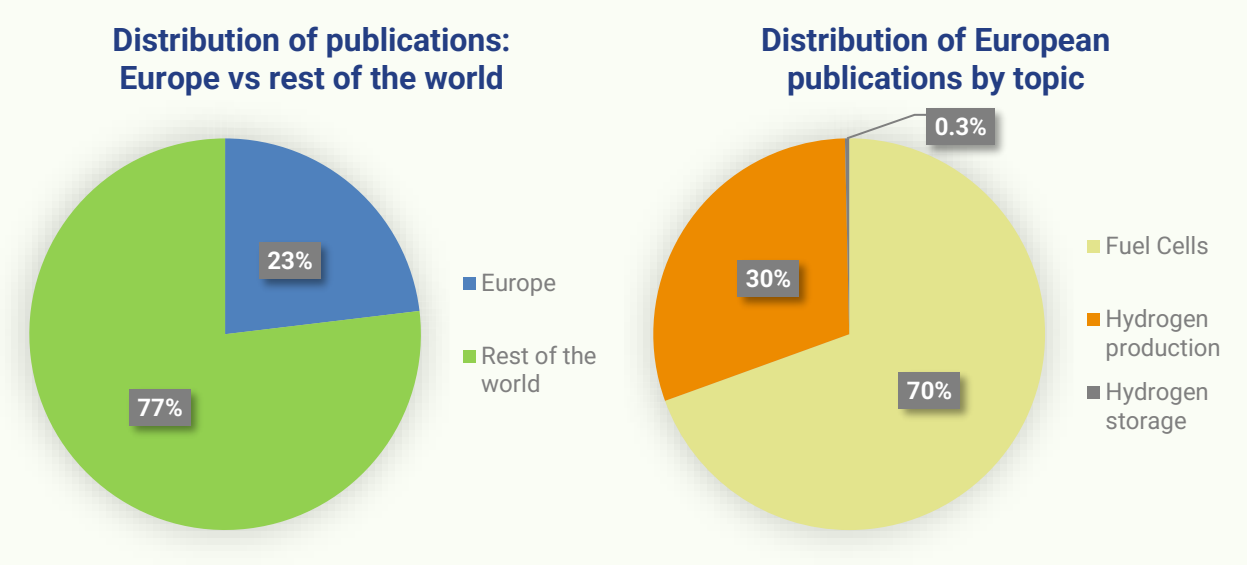


Figure 13. Geographical and topic distribution of publications from 2006 to 2024.

3.1.1.

Publications by topic and technology

Figure 14 presents the distribution of European publications since 2006 by selected topics and technologies. In fuel cells, SO and PEM technologies each account for 32% of total publications (46% of fuel cell-related). Alkaline technologies represent 6%. For hydrogen production, other clean methods lead with 13% of total publications (44% of hydrogen production-related), followed by PEM and alkaline electrolysis at 7%, and SO electrolysis at 3%.Regarding hydrogen storage, only publications related to onboard storage are included and account for 0.3% of the total publications.

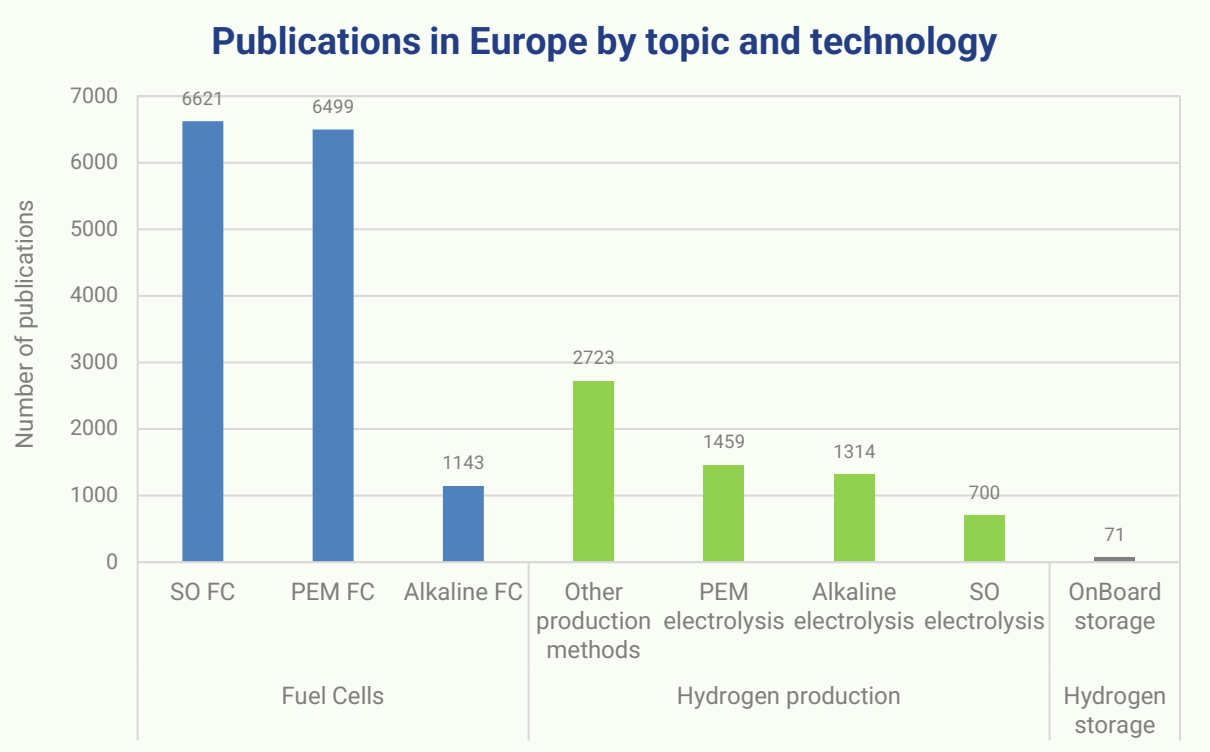


Figure 14. Breakdown of publications in Europe by topic and technology.

Figure 15 presents the historical data on the number of publications for selected topics and technologies in European countries (EU27, EFTA, and the UK) from 2006 to 2023.

The data reveals a fluctuating pattern, with periods of growth followed by declines. However, an overall upward trend in publications can be seen, particularly from 2019 onwards, where significant growth is observed. When looking at the individual technologies, especially a strong increase is observed in publications related to hydrogen production, while for fuel cells it remained constant.

Fluctuations in hydrogen-related publications can stem from varying research funding cycles, technological advancements, policy changes, market dynamics, international collaboration, and media coverage. These factors collectively influence the level of research activity and publication outputs, shaping the observed trends over time.

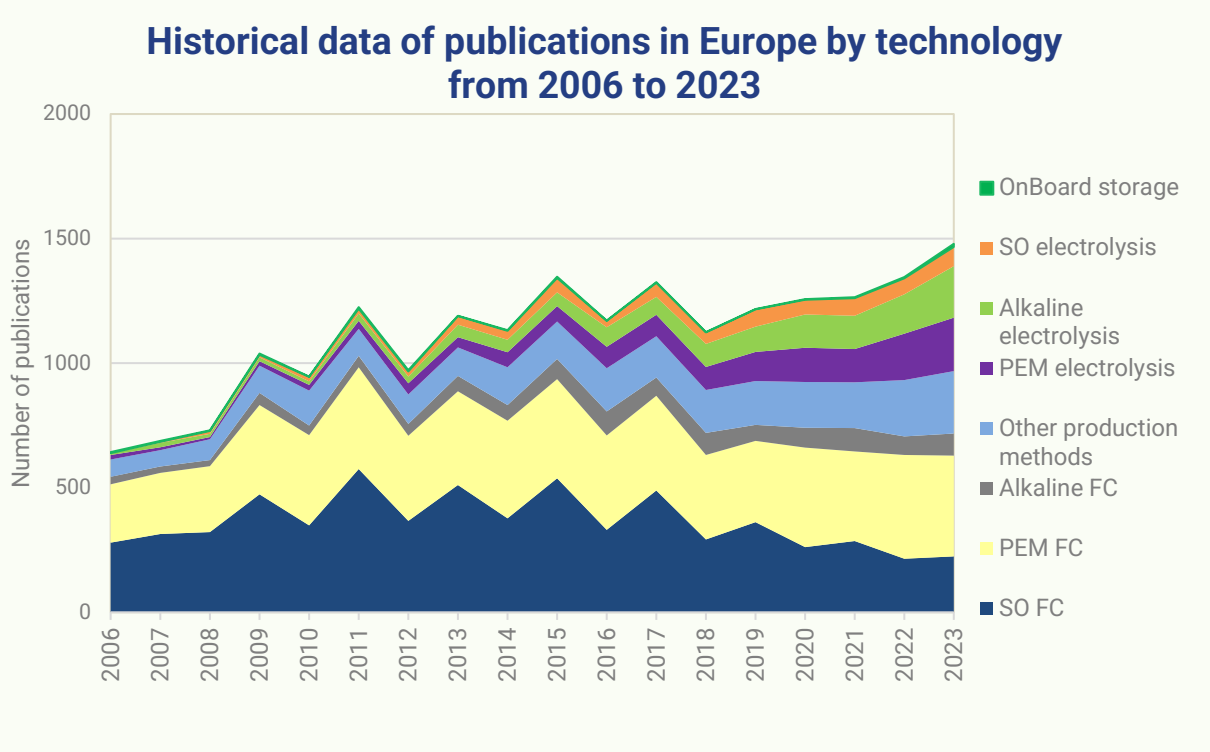


Figure 15. Historical data of publications in Europe by technology from 2006 to 2023.

3.1.2.

Geographical distribution

Figure 16 provides an overview of the geographical distribution of publications in Europe categorized by ranges of publication numbers, while Figure 17 details the number of publications per country and technology, covering the period from 2006 to 2024.

Germany stands out as the leading country with the highest number of publications (3,971), comprising 19% of the total mapped publications. Among the top ten countries with the highest publication numbers are Italy (13%), France (12%), United Kingdom (12%), Spain (8%), Denmark (5%), Poland (4%), Switzerland (3%), Sweden (3%), and the Netherlands (2%).

The remaining countries collectively contribute less than 19% of the total publications. In most countries, Solid Oxide (SO) and Proton Exchange Membrane (PEM) technologies in fuel cells dominate the historic publication landscape.

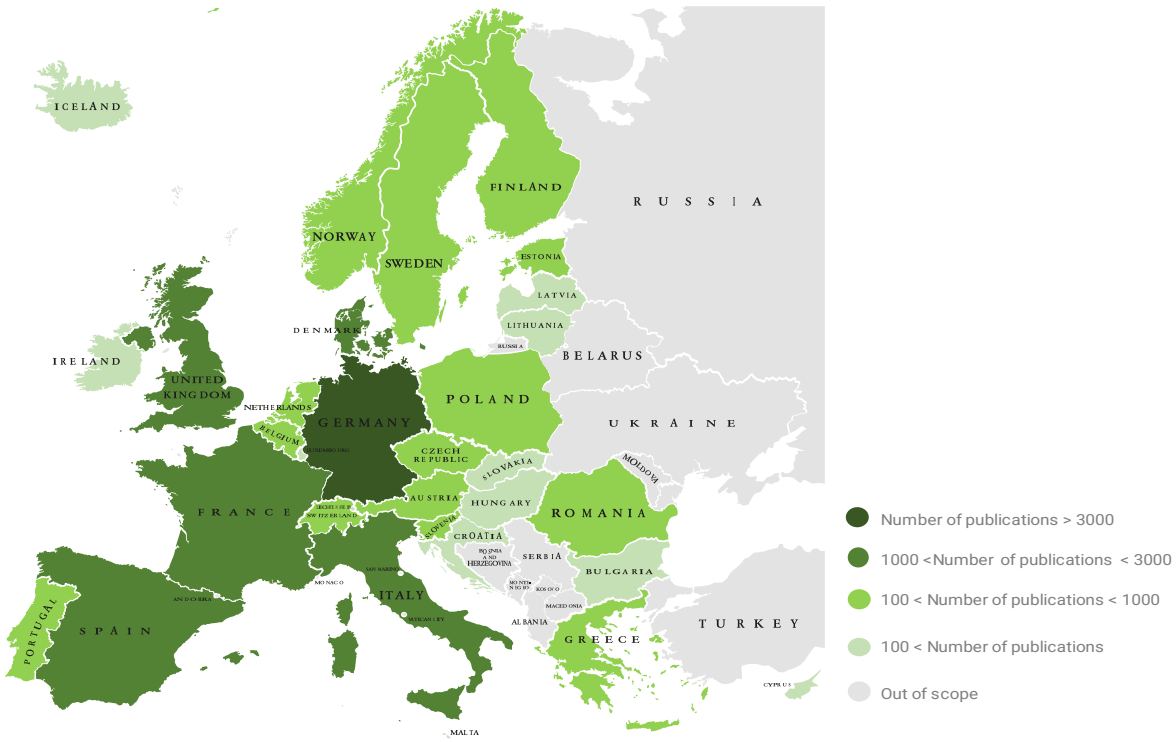


Figure 16. Geographical distribution of publications in Europe by ranges.

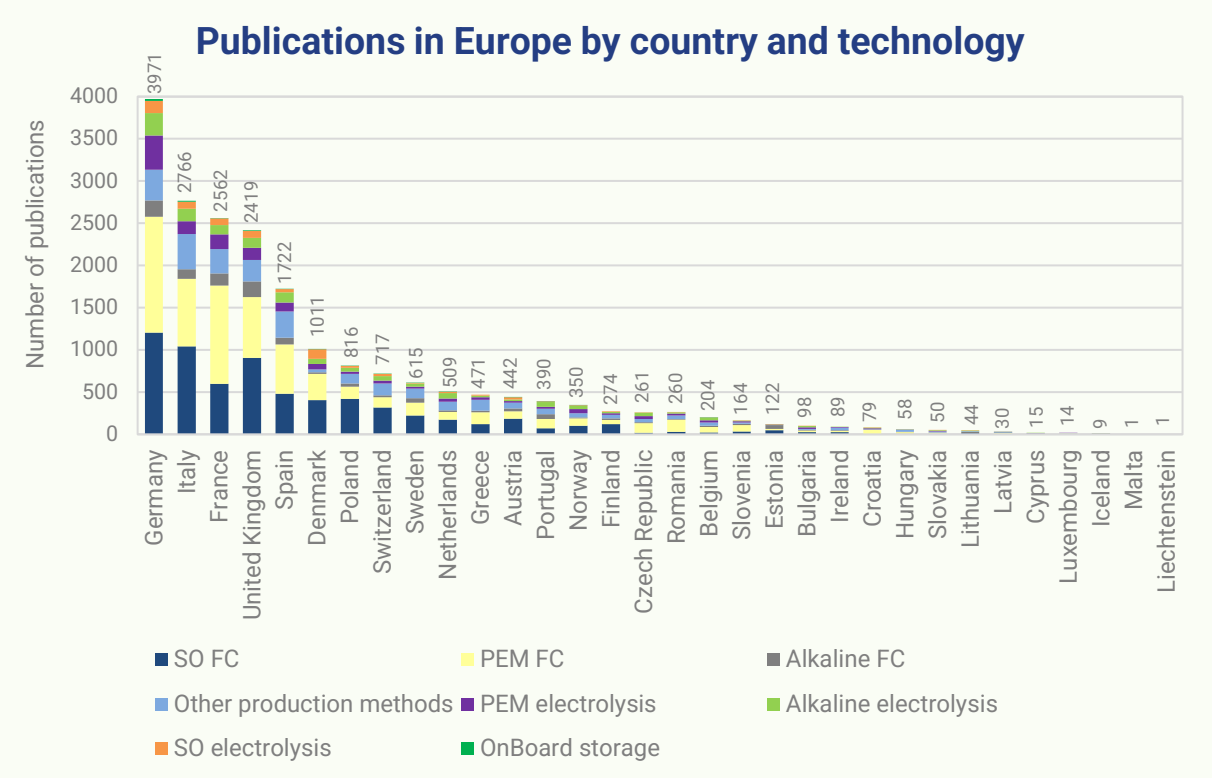


Figure 17. Number of publications by country and technology in Europe.

Figure 18 illustrates the publication trends by examining the evolution in the top 10 countries with the highest number of publications over three consecutive five-year periods (2009-2013, 2014-2018, 2019-2023) by topic.

Out of the ten countries analysed, eight demonstrated an overall increase in the number of publications from 2009 to 2023. The Netherlands experienced the most significant rise, with a 59% increase, followed by Italy with a 39% increase. Germany, Sweden, Spain, the United Kingdom, Denmark, and Poland also saw increases in their publication numbers, with overall rises of 34%, 31%, 14%, 7%, 6%, and 4%, respectively. In contrast, France and Switzerland showed declines in their publication numbers, with decreases of 6% and 0.4%, respectively, over the same period.

However, distinct patterns emerged across the three time periods analysed. Half of the countries examined, namely Germany, Italy, the UK, Spain, and Sweden, exhibited a consistent upward trend in publication numbers throughout these periods. Germany and Sweden experienced the most substantial increases between the first and second periods, with rises of 28% and 25%, respectively. Meanwhile, Italy, the UK, and Spain saw the most notable growth between the second and third periods, with increases of 30%, 6%, and 12%, respectively.

On the other hand, France, Denmark, and Poland, exhibited a different trend. These countries showed an increase in publication numbers from the first to the second time period, with growth rates of 3%, 31%, and 46%, respectively. However, they subsequently experienced declines from the second to the third period, with decreases of 8%, 19%, and 28%, respectively.

Conversely, Switzerland and the Netherlands exhibited an initial decline in publication numbers between the first and second time periods, both experiencing a 5% decrease. However, this was followed by a subsequent increase from the second to the third period, with growth rates of 5% for Switzerland and a significant 67% for the Netherlands.

In the analysis of research trends across various countries, it is evident that publications in the field of fuel cells were predominant, particularly during the first time period. However, there has been a noticeable shift over time, with increasing activity and growing emphasis on publications related to hydrogen production. This trend suggests a broadening of research focus as the importance of hydrogen production gains recognition alongside fuel cell technologies.

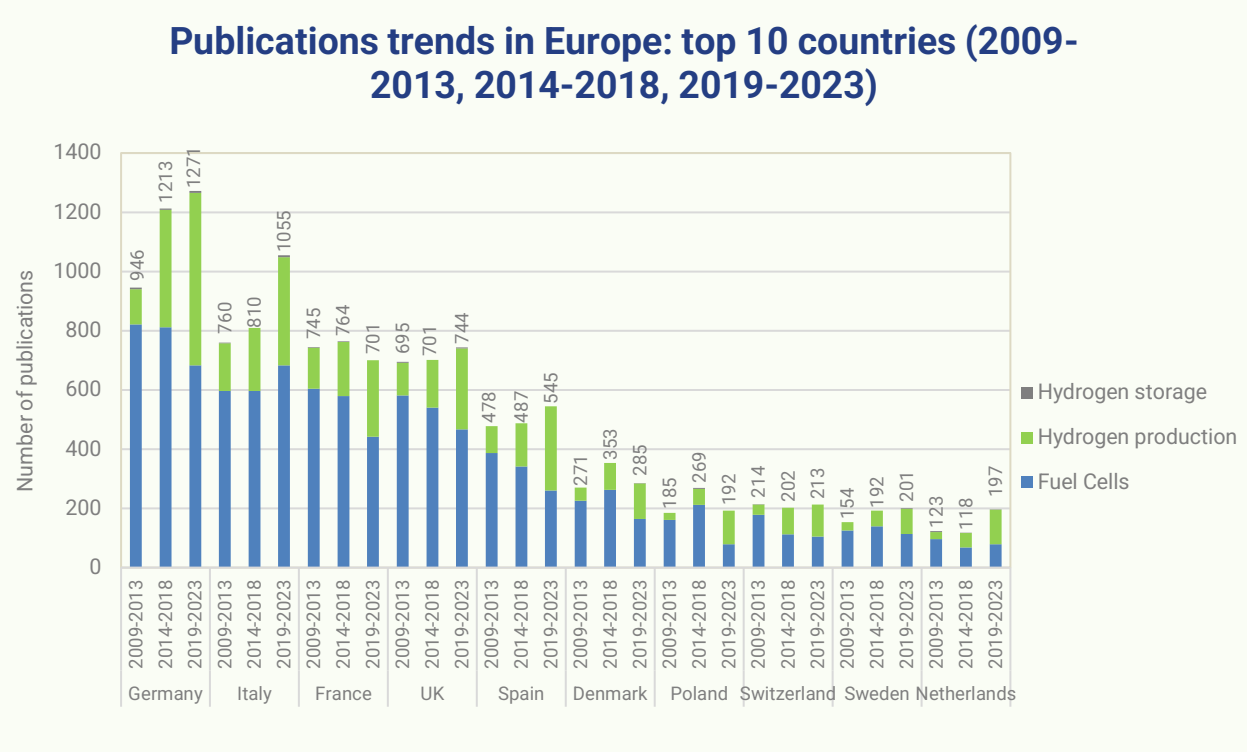


Figure 18. Publications trends in the top 10 countries over three consecutive five-year periods (2009-2023).

3.2.
Patents

3.2.1.
Overview

Patents are monopoly rights granted by Patent Offices in respect of inventions which are new, inventive, and industrially applicable. Patents are territorial and are granted by individual national or regional patent offices in respect of those territories. As such, the geographical extent of filing of a patent application is an indicator of the perceived value an inventor has for the underlying invention.

Almost all countries around the world have adopted a 'first-to-file' system which awards the first inventor to file a patent application at a Patent Office. This means that inventors are encouraged to file patent applications early in the research and development process and, because of this, patent filing statistics are a significant marker of research and development activity. For many inventions patents are the only source of

published technical information relating to the underlying principles upon which an invention is founded.

Patent applications are published eighteen months after filing. In many cases this is the first time the public can see information relating to the invention.

The mapped patent data show the number of inventions in the fuel cell, clean hydrogen production, and hydrogen storage sectors. These numbers are broken down by technology type and year of application, offering a detailed view of innovation trends. By focusing on these specific sectors, the data illustrate the areas where patent registrations are concentrated, revealing the global priorities in developing sustainable energy technologies. This analysis highlights the progress and research efforts in different countries to advance cleaner energy solutions over time.

A total of 12,957 patents worldwide have been identified from 2006 to 2023 in the fields of fuel cells, clean hydrogen production, and hydrogen storage. Figure 19 illustrates the geographical distribution of the patent registrations related to the hydrogen topic, focusing on Europe (EU27, EFTA, and UK) and the rest of the world, as well as the distribution of patents by topic.

Patent registrations in Europe account for a small share, comprising 1,052 registrations (8%) from 2006-2023. Within Europe, the predominant topic is fuel cells, which represent 76% of the patents, totalling 794 registrations. The remaining patents are primarily related to hydrogen production.

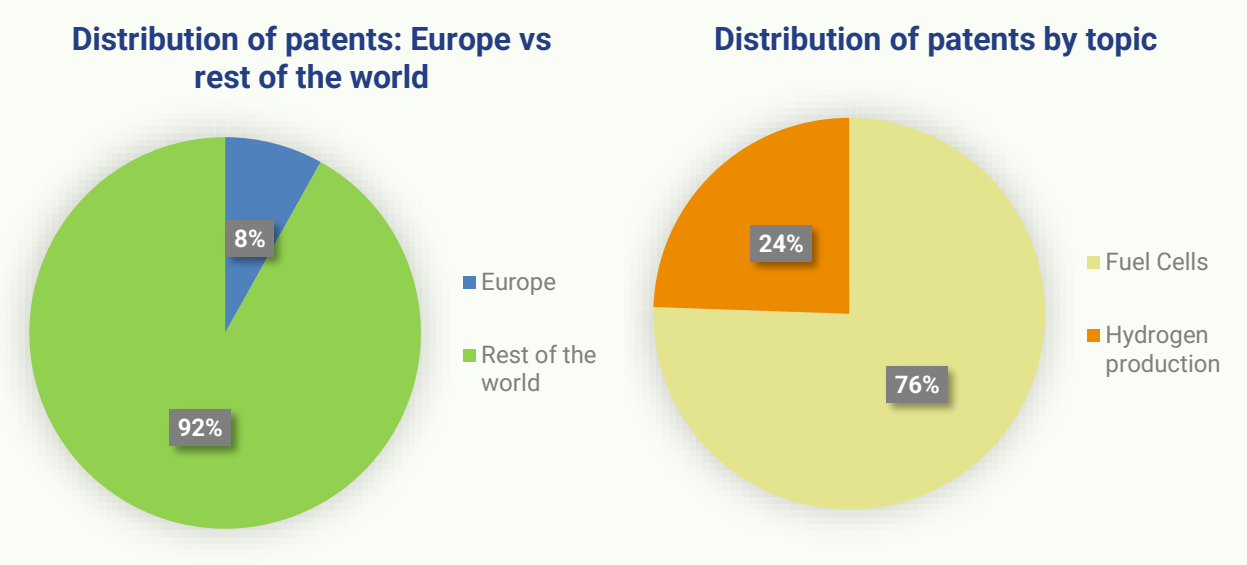


Figure 19. Geographical and topic distribution of patents from 2006 to 2023.

3.2.2.

Patents by topic and technology

Figure 20 presents the distribution of European patents registered since 2006, categorized by selected topics and technologies. In the field of fuel cells, the majority of patents are related to PEM technology, which represents 41% of the total patents and 54% of the patents specifically on fuel cells. The remaining patents in this category are mainly related to SO and in a lower extent to alkaline technologies, totalling 327 and 42 patents, respectively.

In the area of hydrogen production, most patents focus on PEM electrolysis technology, which accounts for 9% of the total patents and 36% of the patents specifically on hydrogen production. The remaining patents in this category are related to alkaline electrolysis, SO electrolysis, and other production methods, totalling 72, 50, and 43 patents, respectively.

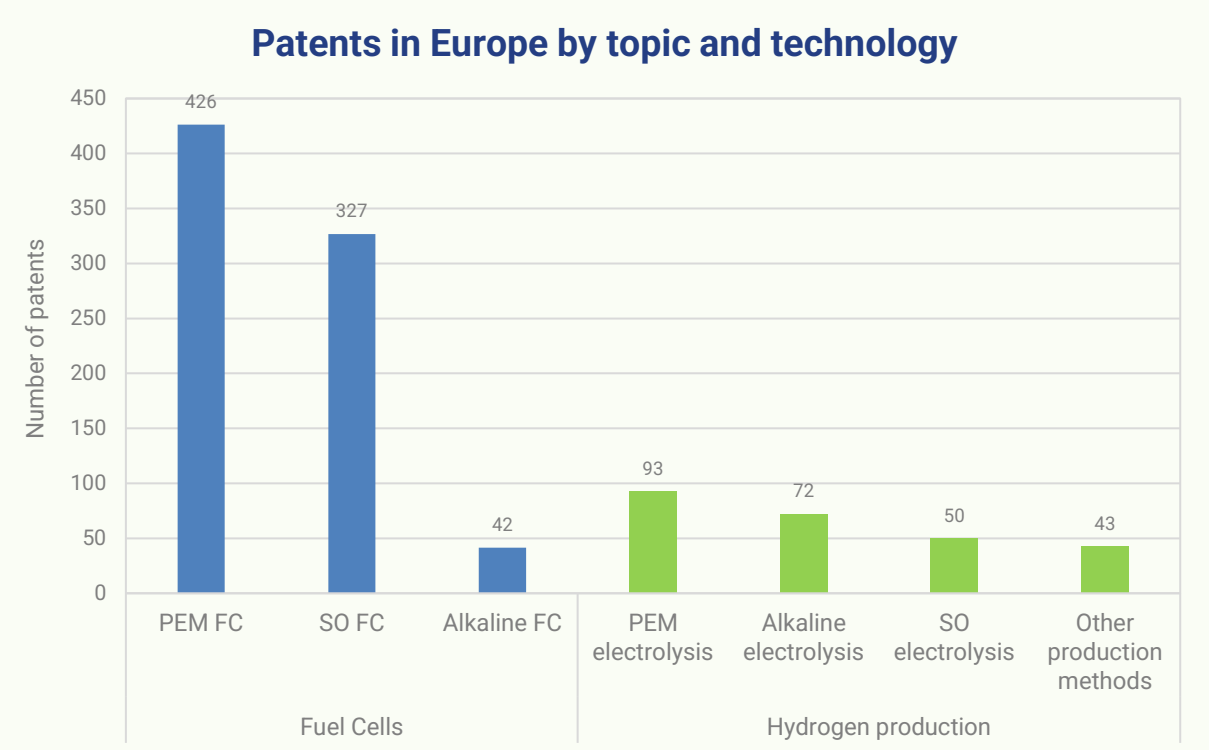


Figure 20. Breakdown of patents by topic and technology.

Figure 21 presents the historical data on the number of patents for selected topics and technologies in European countries (EU27, EFTA, and the UK) from 2006 to 2023.

Overall, there is a declining trend in patent activity, especially for fuel cell technologies, even though there are periods of increasing trends followed by declining trends. Notably, there are

four peaks in 2007, 2012, 2017, and 2021, with 93, 93, 55, and 87 patents respectively.

The sharp drop in the number of patents in 2022 can be attributed to the delay in the patent publication process. Patent applications are published at the earliest eighteen months after filing, resulting in a delay in their appearance in the database. Consequently, data for 2022 and 2023 is not yet complete.

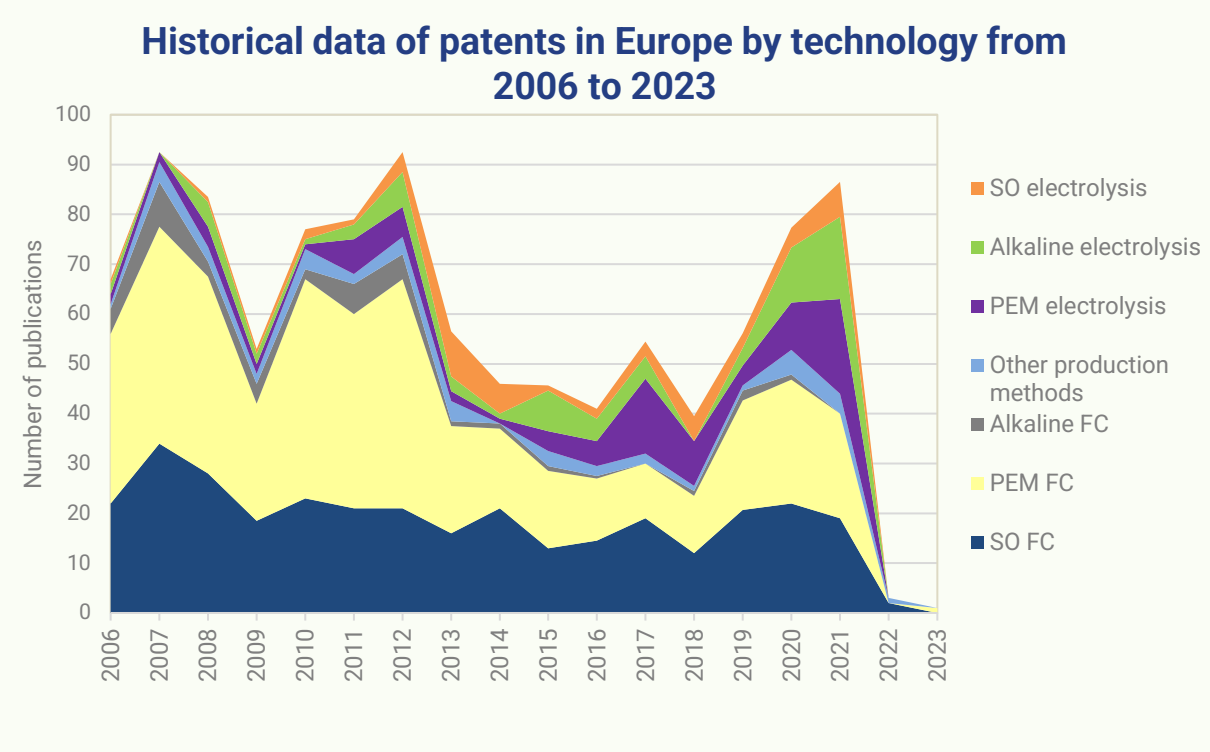


Figure 21. Historical data of patents in Europe by technology from 2006 to 2023.

3.2.3.

Geographical distribution

Figure 22 provides an overview of the geographical distribution of patents categorized by ranges of patents numbers, while Figure 23 details the number of patents per country and technology, covering the period from 2006 to 2023.

Germany leads with 416 patents, representing 40% of the total. Among the top ten countries, France holds 19%, the UK 10%, Denmark 8%, Italy 5%, and Spain, Switzerland, the Netherlands, Romania, and Finland each contribute 2%. The remaining countries collectively contribute less than 8% of the total registrations of patents.

In most countries, Solid Oxide (SO) and Proton Exchange Membrane (PEM) technologies in fuel cells dominate the patent landscape.

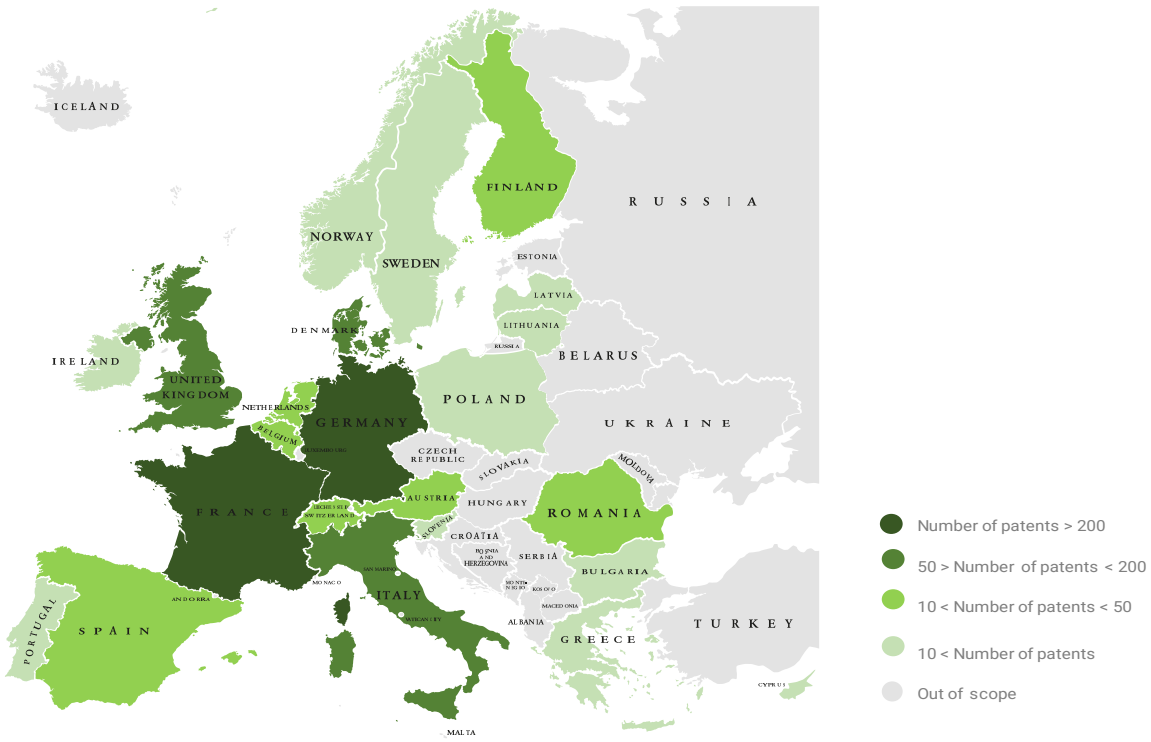


Figure 22. Geographical distribution of patents by ranges.

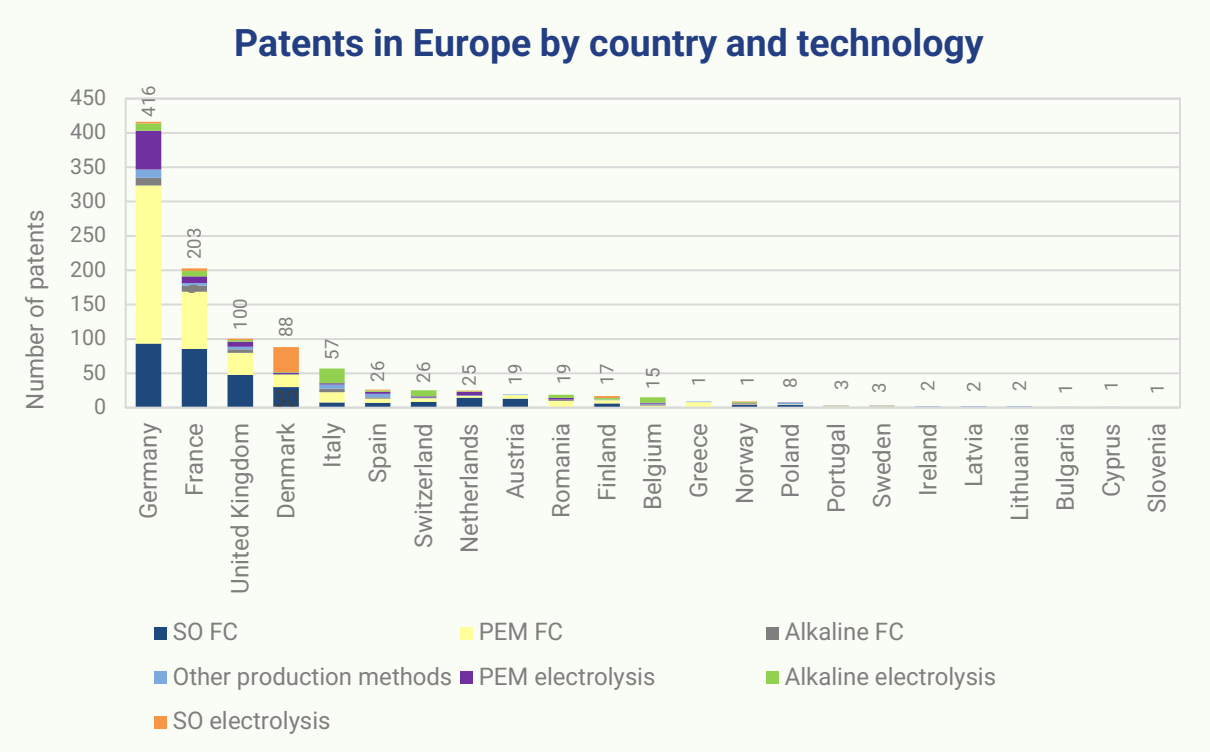


Figure 23. Number of patents by country and technology in Europe.

Figure 24 illustrates the patents trends by examining the evolution of their number in the top 10 countries with the highest number of registrations over three consecutive five-year periods (2007-2011, 2012-2016, 2017-2021).

Trends in patent activity vary by country. France and Italy have experienced a decline, with reductions of 35% and 20% respectively from the first to the last period. In contrast, Switzerland saw a 100% increase from the first to the second period, after which the number remained stable. Other countries, including Germany, the United Kingdom, the Netherlands, Spain, and Romania, initially experienced a drop in patents from the first to the second period (48%, 47%, 93%, 69%, and 75% respectively), followed by an increase in the third period (9%, 181%, 800%, 25%, and 100% respectively).Denmark had a 105% increase in patents from the first to the second period, followed by a 41% decrease.

Similar to publications, recent years have also seen growing interest in hydrogen production in patent activities.

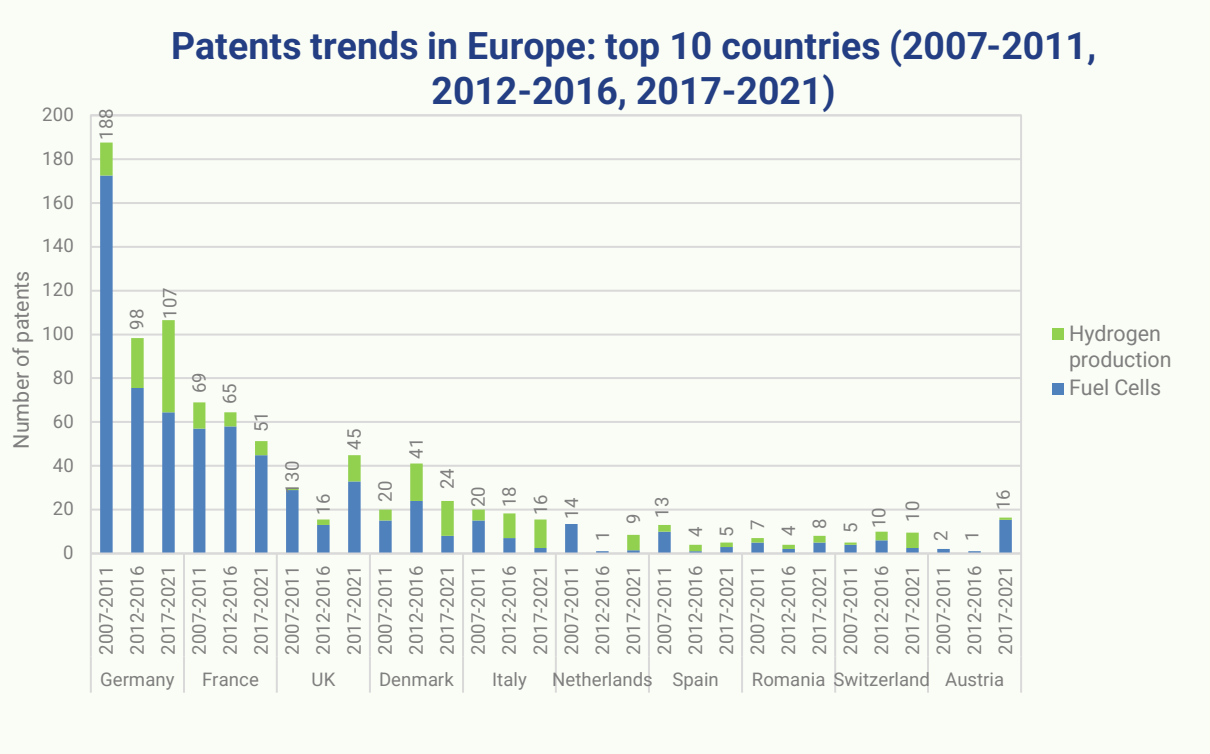


Figure 24. Patents trends in the top 10 countries over three consecutive five-year periods (2006-2021)[3].

[3] Data from 2022 and 2023 were limited and therefore excluded.

Conclusions

The purpose of this report is to provide a comprehensive overview of the latest statistics covering the hydrogen education and research landscape, encompassing training programmes, educational materials, publications, and patents in the hydrogen sector. Previous reports extended their analysis beyond the borders of the EU, offering a global perspective. However, with the relaunch of the European Hydrogen Observatory, the focus has now been refined to concentrate exclusively on developments within the EU. This shift allows for a more detailed and targeted analysis of the EU's progress in hydrogen research and education, facilitating more effective policy-making and strategic planning to advance the hydrogen economy within the region.

Training programmes

In comparison to the previous report, a reduced number of training programmes were identified. This is due to the more focused scope of the EHO database to only bachelor's and master's programmes, professional training courses, summer schools, and vocational education and training (VET) programmes. On the programme level, however, master's and professional training programmes, the two largest programme types, saw significant growth from 2022 to 2024 increasing by over 9% and 14%, respectively, bringing the total to 128 and 83 programmes in 2024.

The registered training programmes are offered in 12 different languages, with English being the primary language in most programmes. The European Hydrogen Observatory now maps 19 countries, with France leading in the number of training programmes offered.

"Hydrogen Production" and "Hydrogen End-Uses: Transport" remain the top focuses among the 11 categories, each representing 69% of training programmes. This is an increase from last year, indicating growing emphasis on these areas.

Education materials

The EHO online library contains 237 reliable materials. The highest number of materials were released in 2024, totalling 50, while the fewest were released between 2015 and 2018, with fewer than five materials each year. Educational materials in 16 different languages are currently listed in the EHO library, an increase from 2022 with the addition of Dutch and Norwegian. English remains the predominant language, available for 84% of the materials, representing a 41% increase from 2022.

Hydrogen end-use applications have become the predominant topic, covered in 36% of the materials. General information on hydrogen is now the second most common topic, included in 27% of the materials. The majority of the materials are intended for audiences with higher levels of understanding, specifically levels 6 and 7, which correspond to bachelor's and master's levels.

Research and innovation activity

Publications and patents registrations in Europe (EU27, EFTA and UK) account for 23% and 8% of those identified worldwide respectively, in the fields of fuel cells (PEM, SO and alkaline), clean hydrogen production (PEM, SO, alkaline and other production methods) and hydrogen storage (onboard storage) from 2006 to 2024. Overall, there is an increasing trend in publications while there is a declining trend in patent activity.

In Europe, fuel cells dominate the research landscape, accounting for 72% of publications and 78% of patents. However, this prominence was more pronounced in earlier years. Recently, there has been a notable shift towards increased activity and a growing emphasis on publications related to hydrogen production. This trend indicates a broadening of the research focus, highlighting the rising recognition of hydrogen production alongside fuel cell technologies.